

CEMENT AND LIME MANUFACTURE

PUBLISHED 20TH OF EACH MONTH.

PRICE 1/- A COPY.

ANNUAL SUBSCRIPTION 12/- POST FREE

PUBLISHED BY
CONCRETE PUBLICATIONS LIMITED
20 DARTMOUTH STREET, LONDON, S.W.1

TELEPHONE: WHITEHALL 4581
TELEGRAPHIC ADDRESS:
CONCRETUS, PARL, LONDON

PUBLISHERS OF
"CONCRETE & CONSTRUCTIONAL ENGINEERING"
"CONCRETE BUILDING & CONCRETE PRODUCTS"
"CEMENT & LIME MANUFACTURE"
"THE CONCRETE YEAR BOOK"
"CONCRETE SERIES" BOOKS, ETC.



VOLUME X. NUMBER 3

MARCH 1937

DESIGN AND OPERATION OF MODERN LIME WORKS—III.*

By N.V.S. KNIBBS, D.Sc.

THE GENERAL DESIGN OF VERTICAL SHAFT KILNS.

MOST of the lime used throughout the world is burnt in vertical shaft kilns, so that this type is of the greatest industrial importance. There are many features of design common to shaft kilns, whether mixed-feed, gas-fired, or furnace-fired, and these features are discussed here.

Raising Stone to Charging Level.

Shaft kilns vary in height from, say, 20 ft. to 100 ft., but modern kilns burning the usual large stone are generally at least 60 ft. high. There are sites so precipitous that the top of the kiln may be reached by a short gantry or even a bridge, as in *Fig. 7*, but they are uncommon and it is generally necessary to raise the stone to the charging point of a tall kiln.

In the majority of lime plants stone of kiln size is loaded on to wagons in the quarry, and it is preferable to tip the contents of the wagons into the kiln so as to avoid double handling. If this is done a vertical hoist, as shown in *Fig. 8*, is generally the best means of elevating the wagons. In the United States an inclined gantry from ground level to the top of the kiln, with rope haulage, is frequently employed. The method is well adapted to feeding a long row of the relatively short furnace-fired kilns, 30 to 40 ft. high, so much used there, but is less suited to tall modern kilns and may require more room than can be spared. Another method that has been used abroad is to lift the bodies off the wagon frames and carry them by ropeway to the kiln tops, but this has little to commend it. Where the rock is crushed mechanically to kiln size the inclined track may be replaced by an inclined belt conveyor fed by the screen following the crusher, and tipping at each kiln in turn, but few plants are large enough to justify this

* For previous articles in this series see our issues for January and February, 1937.

arrangement. In Germany gravity bucket conveyors are used for kiln charging, but they are not well adapted to handling large kiln stone.

Full-size railway wagons are sometimes used in the quarry, and when the latter is remote from the lime plant the stone may have to be conveyed in this manner. It is not usually economic to raise such large containers to the kiln tops and they



Fig. 7.

have to be unloaded and preferably their contents are tipped into a bunker which will feed smaller containers. The inclined charging gear shown in *Fig. 9* is well adapted to such conditions as well as to a plant in which it is desired to have ample stone storage so placed as to be capable of being charged to the kiln with the minimum of labour. It is also applicable to a plant in which mechanical crushing is employed to produce stone of kiln size. The usual arrangement

embodies a balanced double hoist, each skip holding a ton of stone which is tipped automatically at the top and fed into hoppers over the charging doors of two kilns. The hoist is controlled from the bottom and the skips are charged directly from stone storage bunkers. The method is well-adapted to kilns erected in pairs. When the battery comprises more than two kilns there must be a double hoist for each pair, or a travelling hoist of the type shown in *Fig. 10*, which operates in the same manner but is capable of being moved along a track extending the full length of the battery so as to charge any kiln. Alternatively,



Fig. 8.

a fixed hoist may fill a movable charging hopper which traverses the top of the kilns and is discharged mechanically into any one.

The inclined hoist with automatic tip is economical in labour since one man can charge some hundreds of tons of stone in eight hours. It is well suited to feeding gas-fired kilns from storage bins, and may also be employed for the closed-top type of mixed-feed kiln in which all the stone is fed at one point. The majority of plants of small to moderate size located at the quarries are, however, better served by the vertical hoist.

The Kiln Top and Charging Doors.

The top of a kiln may be open, as in many mixed-feed kilns, or closed, as in modern gas-fired kilns and many mixed-feed kilns. Kilns in which the draught is induced by a fan drawing the gases from near the top must have a reasonably tightly closed top to avoid excessive air-inlet leakage with consequent waste of power. It is therefore usual to have a well-fitting door through which to charge the stone, or stone and fuel. The bell type of closure, opening downwards, is convenient, robust, and rapid in operation, so that the kiln is open for only a short time during charging, and it is employed on many plants. The closure is generally fitted at the bottom of a hopper into which the stone is tipped, and



Fig. 9.

it may be operated electrically, hydraulically, pneumatically, or manually, but for hand operation it must be very well balanced, easy to move, and not too heavy. A bell and its seating sometimes tend to wear unevenly and to allow a leakage of air which may be serious. The sliding gate type of closure, like a large gate-valve operating in a horizontal plane, is sometimes used and it may be made so as to allow only negligible leakage, but it takes longer to open and close than the bell, and if it is as substantially made it is more costly. The size of opening required depends on the size of stone being charged; with the stone usual for large kilns it should be at least 30 in. in diameter. When the kiln is charged by a self-tipping hoist the bell or other charging door should

be operated from below by distant control, and this type of operation is employed in the plants shown in *Figs. 9 and 10*. To reduce to a minimum the time the kiln top is open the hopper above the bell or other charging door may be of large size, to hold, say, 10 tons. Mixed-feed kilns with attached stacks for draught are often fed through one or more doors opening outwards at the side near the



Fig. 10.

top of the shaft or in the conical portion which joins the casing to a stack. The slight suction does not necessitate close-fitting doors, and they can be open for limited periods without much effect on the kiln draught.

The voids between stone where it touches a plane surface are greater than in the mass of stone, and consequently there is less resistance to the kiln draught against the sides than over the remainder of the kiln if the whole area is filled with stone of uniform size. In a kiln with an open top small stone may be

placed around the periphery to equalise the draught, and this is often done on mixed-feed kilns. In closed-top kilns, and especially in those operating under induced draught, the same procedure is not practicable, but suggestions have been made for bringing about the same result mechanically. If the charging device is badly designed it may actually tend to accentuate the excessive draught against the wall of the kiln. For example, if a wide kiln is filled through a narrow central opening without a deflecting bell underneath the stone will fall on the centre of a pile heaped at the natural angle of repose, and under such conditions the largest pieces tend to roll farthest and therefore to segregate against the kiln walls. The best means of achieving a good distribution depends on the size of the kiln, the charging and draughting arrangements, and the nature of the stone, and therefore no one device can serve for all conditions.

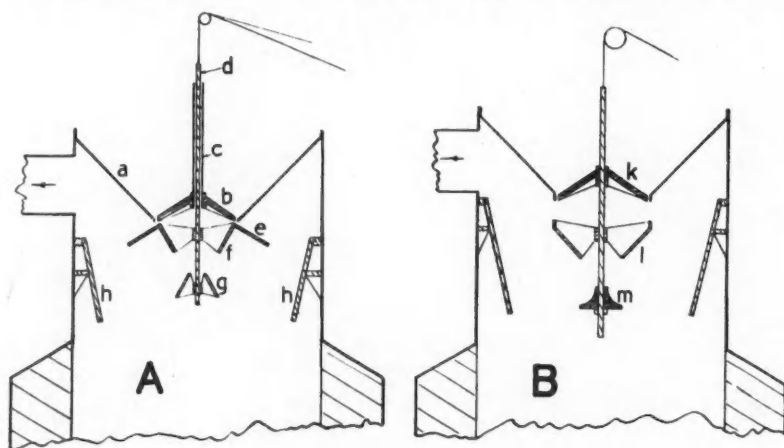


Fig. 11.

One suggestion for positively ensuring the presence of graded small stone near the walls is shown in *Fig. 11*. It is also designed to produce the proper distribution of the fuel in a mixed-feed kiln.

There are two adaptations of the same basic idea (*Fig. 11*, A and B) described in German Patents Nos. 478,532 and 505,096 respectively. In the first (A) there is a hopper (a) and a bell (b) hangs from and is operated by a tube (c). Unlike bells ordinarily employed it is smaller in diameter than the opening in the hopper, and may therefore be raised or lowered. Under the bell and attached to the rod (d) passing through tube (c) (and operated independently) there is a fitting consisting of a hollow conical portion (e) and a funnel-shape portion (f). When (c) and (d) are lowered together, (e) forms in effect a continuation of (b) making it a wide bell, whilst when (c) is raised, leaving (d) in the position shown, (f) becomes a continuation of hopper (a). A hollow conical deflector (g) is also attached to (d), its depth below (f) being adjustable. There is a screen (h)

composed of bars arranged around the periphery of the kiln and slightly inclined to the vertical. In operation, limestone is tipped in to the hopper (a), and (c) and (d) are lowered together. The stone spreads over (e) and is projected against the screen, the small stone passing through it and being distributed around the periphery of the kiln. Fuel is charged separately to the hopper and, instead of lowering (c) and (d), (d) is left stationary and (c), with the bell (b), is raised. The fuel therefore falls through (f) and meets (g), which spreads it over the kiln, whilst a portion falls through to supply the centre. The height of (g) is adjusted to suit the fuel and to spread it a little short of the full width, so that there is none in contact with the kiln walls.

In the second and later form (*Fig. 11, B*) the double operating gear is discarded and the bell (k) and funnel (l) are attached to the same rod, whilst the lower deflector (m) has no central passage. When charging stone the bell is lowered and the stone spreads sufficiently to meet the screen. When charging fuel it is raised until the funnel (l) meets the hopper, and the fuel drops through it and is distributed by (m), which again is adjustable in height.

The first arrangement is better adapted to kilns of large diameter, but the second and simpler gear is ordinarily sufficient.

The Shell of the Kiln.

The shell or casing of a shaft kiln serves to encase and support against outward pressure the refractory lining and any insulating material that may be used, and to provide support for the superstructure, charging and inspection platforms, etc. It may be made of steel, concrete, stone, or brick. There are many masonry kilns still in use, but stone is now too costly to employ, and as under present conditions concrete is cheaper and better than brickwork modern kilns are almost invariably encased in steel or concrete.

A concrete casing is cheaper than one of steel and it has been used in the construction of many mixed-feed kilns where there is only a simple superstructure and no side platforms, inspection and poking holes, etc. Reinforced construction is to be preferred, and it should be designed to reduce to a minimum the risk of shrinkage cracks in the structure. To avoid leakage through any cracks that may occur it is desirable to have sand or other loose material as a filling between the concrete shell and the refractory lining. It is also necessary to insulate the wall to avoid overheating the concrete, and this entails a greater thickness of the insulating layer. The concrete may be from about 6 in. to 18 in. thick, and this, when added to the extra thickness of insulation, gives a total wall thickness much greater than that of a steel-encased kiln. As a consequence, access ports for inspection or poking are much deeper and therefore less effective. This disability, combined with the greater difficulty of satisfactorily fixing the poking or inspection door frames to the concrete structure, tends to render concrete an unsuitable casing material for kilns in which side doors are necessary.

The steel casing of a kiln is made up of plates between $\frac{1}{2}$ in. and $\frac{3}{4}$ in. thick, riveted or bolted together. It generally terminates at the bottom in a heavy angle ring which is carried on the concrete foundation. If it is heavily loaded

at any point it may be stiffened and the load distributed by heavy steel tee-sections or channels fixed vertically on the outside surface. In closed-top kilns special attention should be paid to the design of the top to ensure sufficient stiffness to carry the superstructure and the bell or other charging device with its operating gear, and also to ensure that no parts of the steel casing exposed to the action of the kiln gases can become cool enough for water to condense on them, otherwise there will be serious corrosion.

Inspection and poking doors should be of substantial construction, accurately made to ensure an air-tight closure, and preferably of good quality cast iron. Whether it is necessary to line them with refractory insulating material depends on the area exposed to the heat of the kiln. A door in the burning zone with an exposed area of more than about one-quarter of a square foot should generally be lined.

Access Platforms, Housing, etc.

Practice varies widely in the provision of platforms attached or adjacent to the shells of lime kilns. Short mixed-feed kilns in which all the fuel is mixed with the stone at the top are seldom provided with inspection platforms, but modern tall kilns, and especially gas-fired kilns, generally have two or three platforms at different heights providing access all around the kiln, with inspection or poking doors or both at each level. When a kiln is being operated steadily it may run for weeks without there being any real need for such doors and platforms, but in starting up, and if trouble arises, they are of constant service. From the point of view of operation the more points of access that there are to the interior the easier it is to control the kiln, but two considerations, namely, the added capital cost and the undesirable discontinuities in the refractory lining that they introduce, limit the number. Further consideration will be deferred until the design of the different types of kiln is under discussion.

Where there is an inspection door it is desirable that there should be a platform suitably placed to permit its easy use, and where there are poking doors a platform at convenient height and of ample width is essential. When the kilns are built in pairs, or several are placed close together in line, the platforms may span the gap between them to give easy access.

There are various opinions as to the housing necessary or advisable on lime kilns, but in Great Britain the modern tendency is to house the plant sufficiently to permit comfortable operation at all important points. *Figs. 7 to 10* illustrate plants variously enclosed. When the stone is charged from wagons taken up in a vertical hoist it is desirable, for comfortable operation, to cover the kiln tops as in *Fig. 8*. When a self-tipping skip hoist is used, as in *Fig. 9*, or a grab that may be tripped from below, housing the top is superfluous. *Figs. 9 and 10* show plants covered in at all points where in normal operation anybody has to work. Corrugated-iron or asbestos-cement sheets are generally used for housing, while steel-frame windows should be sufficiently numerous for admission of daylight to all working places. If iron sheeting is used the kiln exhaust should be carried well away from it to avoid corrosion.

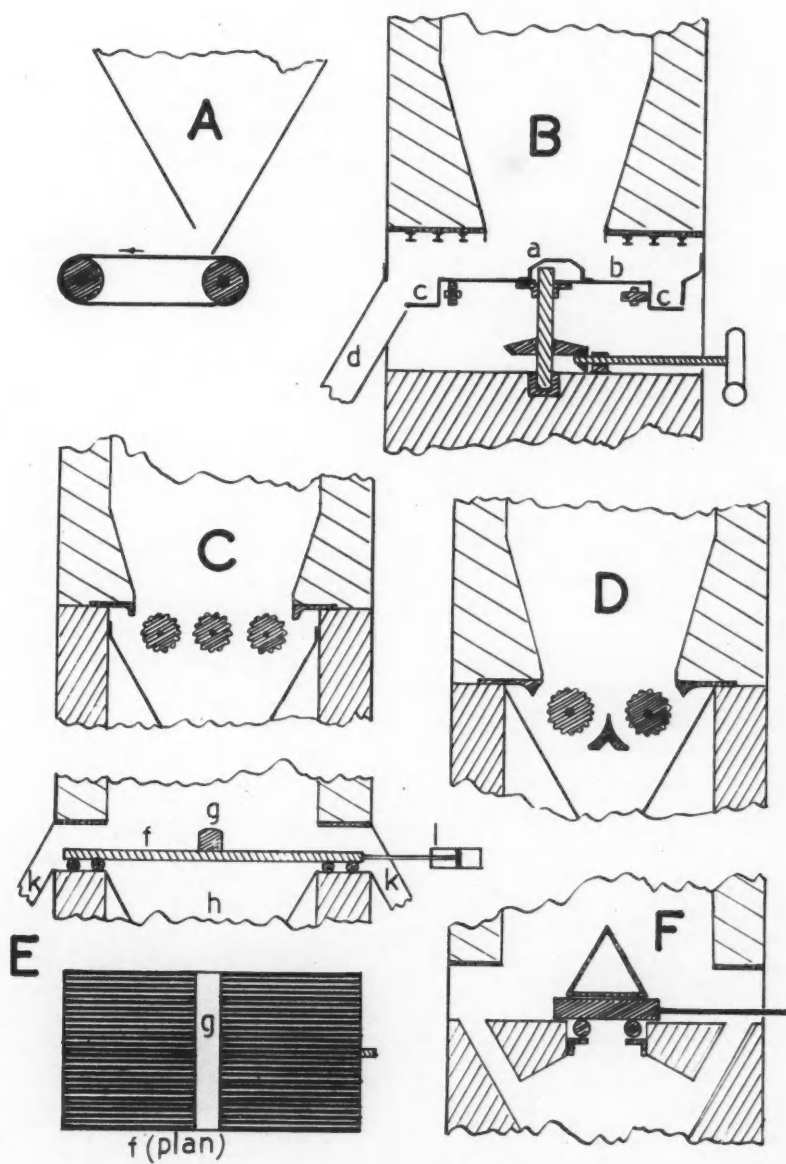


Fig. 12.

Discharging.

Lime kilns may be discharged intermittently or continuously, and both types of discharge are used, but the latter is comparatively rare in Great Britain and in some instances it has been discontinued. On kilns of large output there are distinct advantages in having continuous discharge, but experience has shown that the continuous dribble of lime from a kiln tends to result in uneven following down of the burden in the shaft when the lime is near the temperature at which it "sticks." For economy of operation kilns are generally worked as close to this temperature as possible, but on a kiln run at a lower temperature continuous discharge would probably be entirely satisfactory. Mixed-feed kilns which are discharged during the eight-hour day shift only are sometimes fitted with a continuous discharge, and the greater rate of flow that results from the concentration of twenty-four hours' burning into eight hours' discharge is in its favour. The lime may conveniently be fed directly from the discharger on to a sorting belt: in fact, the simplest continuous discharge is a conveyor drawing from the bottom of the conical base of a kiln, as shown diagrammatically in *Fig. 12 (A)*, or fed on to the conveyor by a Ross feeder.

Most of the continuous discharging devices for lime kilns have been developed in Germany, and a full account of them will be found in Klehe's "Das Kalkwerk," but they are usually adaptations of known devices used for similar purposes. They may be divided into three groups, embodying the principles of the rotary grate, the toothed roller, and the reciprocating feeder. *Fig. 12 (B)* shows diagrammatically what is perhaps the best type of rotary discharge. The eccentric flattened cone (a) on the slowly rotating table (b) pushes the lime over the edge of the table on to the apron (c) which is also rotating, whence it is scraped by a plough (not shown), to fall into the chute (d). It is driven through reduction gearing. This type of discharge has been used in Germany and America. Several other types of rotary discharge have been proposed, but most of them crush the lime more and have no particular merits. *Fig. 12 (C)* illustrates the principle of the toothed-roller type of discharge, with three rolls which slowly rotate and through which the lime is forced and discharged, necessarily with considerable crushing of the larger lumps. The number of rollers may be varied but would seldom exceed four. *Fig. 12 (D)* shows a two-roll modification with a fixed baffle-bridge between them. It crushes less but does not discharge so evenly. The reciprocating type of discharge may take the form of a grizzly (f) moving slowly backwards and forwards under the kiln shaft, as in *Fig. 12 (E)*, and having a raised blank portion (g) at the centre. The small lime falls through into a hopper (h) and the lumps discharge over each end through chutes (k) into trucks. The motion is supplied by a reciprocator (l) which may operate hydraulically or mechanically. Alternatively, a slowly reciprocating ram, as in *Fig. 12 (F)*, may push the lime across the horizontal base of the kiln and down two chutes. Obviously neither of these two devices ensures the even discharge of a kiln over the whole area, but they are said to operate efficiently.

All these continuous discharge devices, except possibly the first, break up the lime to some extent, but with the increasing use of hydrate this objection is losing its cogency and their use will undoubtedly increase. To vary the rate of discharge they are driven by variable-speed motors, or through speed-variation gear.

The arrangements on kilns using intermittent discharge are many and varied. A conical bottom with a discharge door at the apex of the cone and at a height

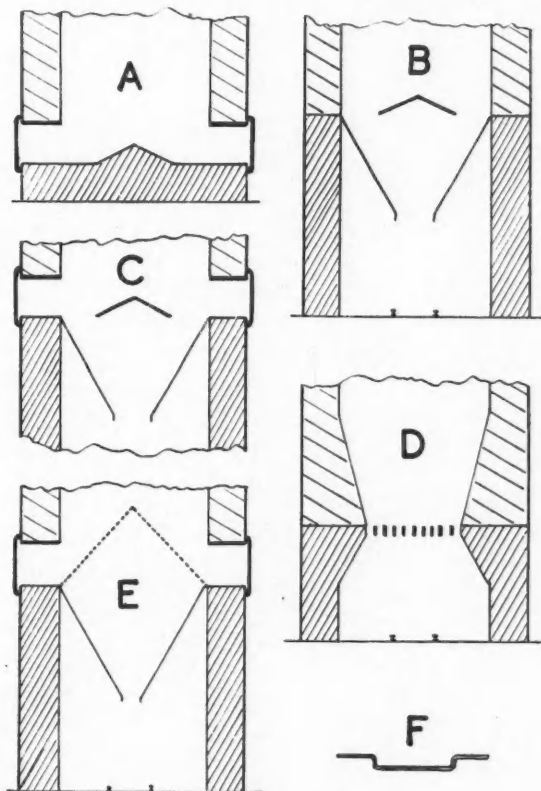


Fig. 13.

to feed into a truck or on to a sorting belt is clearly a very convenient form of discharge, but, since most kilns tend to become hotter near the walls than at the centre, side discharge is an advantage and is often employed, as in *Fig. 13 (A)*. The advantages of the side and the central discharge are combined in the arrangement shown diagrammatically in *Fig. 13 (B)*, which is used in many gas-fired kilns. One advantage the side discharge alone has is that the kiln may

be drawn from more heavily at any desired point to overcome uneven heating. To enable the same thing to be accomplished with central discharge it has been proposed to have access doors in the kiln opposite the inner cone, as shown in *Fig. 13 (C)*. Steel bars are thrust through the lime so as to span between the cone and the side door and to hold up the lime above. The device is clumsy but effective as an occasional expedient. Many mixed-feed kilns have the discharge arrangement shown in *Fig. 13 (D)*, or some modification of it. The lime rests on movable bars and is let through them in to a wagon below by moving the bars together in pairs or by giving them a quarter twist, or otherwise. It is not a convenient form of discharge, but allows even air distribution. *Fig. 13 (F)* shows another form of bar used in the same way. A small angular twist of this bar leaves a wide opening for the passage of the lumps.

Many mixed-feed kilns are fitted with a screening surface at the bottom so that the fines are separated from the lumps before or during discharge. The screen may also serve as an inlet surface for air, and is an efficient distributor. The simplest form is that shown in *Fig. 13 (E)*, where the lumps are withdrawn at side doors and the fines fall through into a hopper bottom, but there are numerous variations of the same idea. The device has some value on small plants, but is of doubtful value in large plants where the separation is best effected after withdrawal from the kiln in lime-handling plant which will be considered later.

The Draught.

All modern gas-fired kilns are operated under draught induced by an exhaustor, but mixed-feed kilns are still extensively worked under natural draught. The draught due to the kiln shaft is generally supplemented by a stack, but there are still many old kilns at work with open tops without a stack. They may be omitted from a consideration of modern plant. Mixed-feed kilns with enclosed tops working on natural draught often have a conical top terminating in a stack, which is seldom high enough to have much effect on the output of the kiln but reduces the variation in the draught caused by wind and provides a slight suction at the charging doors so that feeding the kiln is safer and less unpleasant. Where open-top kilns are preferred because of the better placing of stone and fuel they allow, a clear atmosphere may be obtained by using a submerged stack which draws from the centre of the kiln at a position well below the top of the stone.

Kilns may be operated under forced or induced draught. To provide a kiln with air under sufficient pressure to give the required output of lime requires only a fraction of the power—generally about one-third—of that taken by an exhaustor inducing the same draught. The air blower has less volume to handle at a much lower temperature. Furthermore, the volume delivered by an air blower varies only slightly with change of air temperature, while the exhaustor volume is liable to wide variation due to the variation possible in the kiln exhaust temperature. Again, the rate of flow of clean cold air is readily measured so that the volume, and therefore the output of the kiln, is easily checked and controlled, whereas to measure the exhaust by meter is much more difficult

and each reading must be the subject of a calculation to correct for temperature. From the points of view of control and of power consumption, therefore, forced draught has great advantages over induced draught.

There are two difficulties with forced draught which have limited its use. First, it necessitates having a tightly closed bottom section of the kiln with a tight discharge door. Absolute air-tightness here is impracticable, and unless the discharge arrangements are carefully planned and constructed the leakage of air may entirely eliminate the advantages of the system. Given tight discharge doors it is easy to apply the system to the arrangements shown in *Fig. 13* (B and E), air being blown under the conical baffle and into the conical bottom under the screen with the side doors tightly closed, respectively. The second difficulty is that forced draught results in there being a pressure in the lower section of the kiln, so that there is a blow-out at any inspection door in that section. This is particularly objectionable in a producer-gas-fired kiln because the gas must then be introduced at considerable pressure and the producer operated at a corresponding pressure. It is less objectionable in a kiln fired by natural gas, coke-oven gas, or blastfurnace gas, and still less in a mixed-feed kiln. In any kiln, however, inspection of the burning zone through inspection doors is rendered difficult by an outrush of hot gases and it is necessary to stop or damp down the blower when looking into the kiln. In spite of these drawbacks the advantages of forced draught on mixed-feed kilns are so considerable that it could with advantage be much more used. It is used on the Continent at a number of plants.

The temperature of the gases leaving a kiln varies between wide limits. The gases of a chalk kiln, burning wet chalk, seldom rise above about 150 deg. C. and often they are so close to the dew point that condensation takes place in the pipes and exhauster, which must therefore be designed to resist corrosion. The exhaust of a limestone kiln operating continuously may be at anything up to about dull red heat, and that of a mixed-feed kiln which is drawn on day-shift only may be still higher in the morning before charging, but such kilns are seldom mechanically exhausted. Normally, however, the outlet temperature of a continuous kiln does not exceed 400 deg. C. at the peak temperature. Exhausting fans will operate at this temperature but their life and efficiency are poor. If the gases are passed through a waste-heat boiler their temperature is reduced, the exhauster operates more efficiently and at lower temperature, and on a producer-gas-fired plant the steam for the producers is provided without extra fuel. Modern producer-gas-fired plants when operating on limestone therefore include waste-heat boilers between the kilns and the exhausters.

The design of the outlet for the gases from a shaft kiln with closed top is of considerable importance. *Fig. 14* illustrates diagrammatically six different types of outlet. The simplest is that shown at (A), where the natural angle of repose of the stone charged at a central opening leaves an annular space from which the gas off-take draws. With a bell-charging gear the spread of the stone prevents the formation of the annular space but by lengthening the seating of the bell into a sleeve an annulus is formed (as at B) which is equally effective.

It is sometimes held that, even with adequate annular free space, the withdrawa from one side causes uneven draught up the kiln, and to equalise it the gases are withdrawn from two or more points around the kiln. Another arrangement is shown at (C), where the annular flue is built in the brickwork at the top, connection to the kiln shaft being effected by a number of small passages spaced equally around the kiln. It is effective in ensuring an even pull all around if the resistance

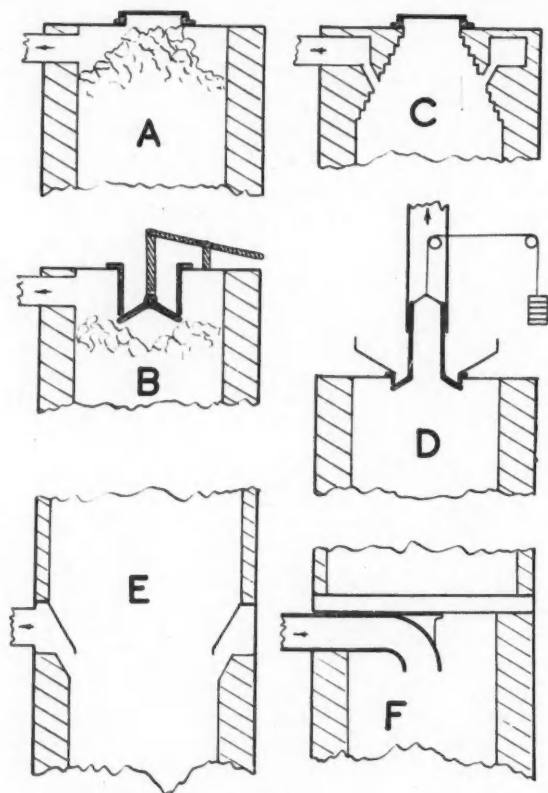


Fig. 14.

through the small openings is large in comparison with that through the annulus itself. A central draw-off from the top of the kiln is complicated by the kiln charging arrangements, but at D is shown how it may be accomplished. The charging bell forms part of a cast-iron exhaust pipe which is free to move up and down in the exhaust stack, the fit being good enough to make leakage only slight between the bell tube and the stack. The stack is supported by a steel superstructure not shown.

When the gases are to be withdrawn at a point below the top of the kiln an annular space may be formed as in *Fig. 14 (E)*, from which one or more exhaust pipes may lead. A central draw-off is shown at (F) but the pounding of the limestone and the possibility of its being subjected to considerable heat make it necessary to use heavy supports for the central draw-off tube.

Many arrangements have been suggested for preheating the air for lime kilns by drawing it through a system of flues arranged in the kiln lining. If air is preheated and introduced at the bottom of the cooling zone the effect is to decrease the cooling of the lime and therefore the recovery of heat from it. It is necessary, therefore, to introduce the air at some point in the burning zone or just below it, and the usual practice is to terminate the preheating flues at a number of ports in the lining leading in to the kiln about half-way up the shaft. Since excess air generally finds its way up the walls in any kiln, this scheme merely accentuates a fault. Ordinarily, however, the various ports and flues rapidly become blocked and play no further part in the kiln operation.

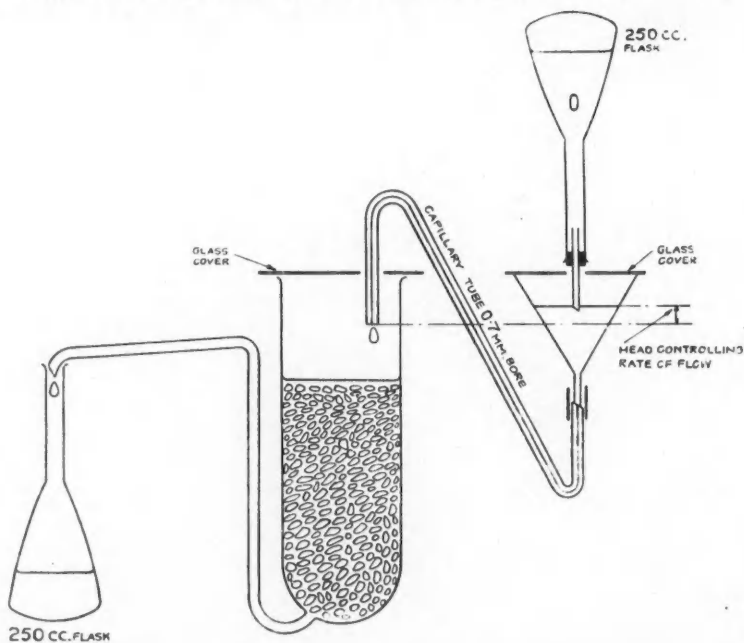
Theoretically, the abstraction of heat from the burning zone to preheat air can do no good. It is sometimes contended that the cooling of the refractory lining by the air channels increases its life, but the structural weakening consequent upon the introduction of enough channels for even cooling would do more harm than any possible benefit from cooling. In one type of mixed-feed kiln—the modified Aalborg kiln of which the Spencer kiln is representative—there may, theoretically, be some benefit from air preheating by the kiln lining. This will be considered subsequently.

(*To be continued.*)

Apparatus for Studying the Effect of Aggressive Solutions on Mortar.

By D. IRVINE WATSON, B.Sc., A.I.C.

THE importance of obtaining reliable information on the resistance of various types of mortar to the action of soluble sulphates and other aggressive solutions is now well recognised. It would seem a simple matter to expose concrete or mortar made with various cements to the action of a soluble sulphate under controlled conditions, and thus obtain definite information as to the relative value of the cements from this standpoint. In practice, however, it is a difficult



matter, and fair comparisons can only be made if the concrete is made and cured under large-scale practical conditions. Much of the work which has been published relates to laboratory-prepared mortars made and cured in a special way, which contain types of sand seldom used in practice, and which contain less cement than would be used in normal concrete. This has been rendered necessary by the fact that specimens must be strictly comparable and of reasonable size, and also by the need for obtaining results within a comparatively short time. A large amount of work carried out on similar lines has convinced the author of the unsatisfactory and conflicting nature of the results obtained.

For these reasons a simple apparatus now used by the author in the study of such problems is here described. No extensive amount of work has yet been carried out with the apparatus, but it is hoped that other investigators will find sufficient merit in it to enable them to adopt it. It is designed so that work can be continuously carried out with it in a laboratory without the expenditure of much time, and it is thought that if tests are undertaken on similar apparatus in other laboratories much useful and comparable information will be available in a few years time.

In using the apparatus, the sample of concrete to be examined is broken up, the larger stones removed, and the test carried out on mortar granules passing a $\frac{1}{8}$ -in. sieve but retained on a $\frac{1}{16}$ -in. sieve. The sample must be transferred to the apparatus before any change such as carbonation has taken place by exposure subsequent to breaking up, or the test will not be carried out on mortar as it exists in the concrete. If the apparatus is adjusted to pass 250 cc. of aggressive solution in three days it will be found to need practically no attention. The progress of the attack is followed by periodical analyses of the liquid which has passed through, and finally by running distilled water through for the last two weeks to enable an analysis of the washed mortar residue to be compared with that of the original mortar.

In order to appreciate the advantages claimed for this process it is necessary to note a few of the difficulties experienced in former work. The total immersion of laboratory specimens, for instance, introduces uncertainty as regards (1) The relative permeability of specimens; (2) The nature of the exterior surface of specimens; (3) Relative flow conditions; and (4) Failure to remove the products of reaction from the solution, or perhaps their intermittent removal. Partial immersion of specimens introduces physical disintegrating effects which, although serious in practice, must be studied separately. Other work has been carried out on powdered mortar and even on powdered set cement, but it has been found that the relative order of merit of three special cements when tested in this manner was reversed according to whether the ratio of liquid to powder was high or low. Many other difficulties, which are well recognised, could be cited from published work.

The advantages claimed for this apparatus are: (1) The concrete to be tested can be made in a commercial way and cured as required; (2) The slow flow and continual introduction of fresh solution are in close accord with practical conditions; (3) Variations in the permeability of the mortar tested have much less disturbing influence on the results than when solid specimens are used; (4) The ratio of liquid to mortar corresponds reasonably with practical conditions; (5) All surface effects are avoided; and (6) Attack due to physical causes is eliminated.

In general it is suggested that this method of test approaches the conditions of practice very closely and that the most important variable, namely, accessibility of the constituents liable to attack, is standardised at a point which gives accelerated results without materially affecting the reproducibility of the results.

Conveying and Elevating in the Cement Industry.

CONSIDERABLE progress has recently been made in the use of the Redler "En Masse" system of conveying and elevating in the cement industry. During the past two years successful tests have been made under working conditions on quantities up to 50 tons per hour.

The system comprises a trough with a skeleton chain working therein and is capable of carrying a load of a depth approximately equal to the width of the chain. The load travels at the same speed as the chain in an undisturbed mass, and the system is therefore particularly applicable to the cement and lime industries for conveying horizontally, on an incline, or vertically. For vertical conveying specially designed chains are used to sweep three or more sides of the inner surfaces of the casing, the trough being totally enclosed. During the course of conveying the material is made to flow like a liquid by the use of mechanical methods which co-operate with the natural behaviour of the material and induce it to flow in the required direction.

These machines are also particularly suitable in the coal preparation plant and the handling of the finished product, as well as for other purposes.

Different types of Redler machinery may be used to elevate coal from barges or from under railway wagons, to distribute it to the storage bunkers, to draw it from the base of the bunker and convey it directly to the feed hoppers of the pulverisers, to take the pulverised coal direct to the burner, or to abstract it from the surge tank and feed it in measured quantities to the burner. In cases where it is desired to use individual pulverisers for each kiln, a feeder may be used to give a constant controllable supply of fuel. The system is wholly automatic, and incorporates bin level indicators which register when the rise or fall of the fuel is below a certain level and a radiovisor to control the feed of conveyors.

When tested under practical conditions in a cement works a 17-in. "Uniflow" conveyor ran for 5,650 hours, the chain speed being 13 ft. per minute and the capacity 40 tons per hour. During the tests it handled 174,125 tons of cement, and the cost of maintenance was nil. The most wear occurred on the runners carrying the return chain, and this was in the neighbourhood of forty-five thousandths of an inch. The aim of the manufacturers has been to produce a machine capable of running continuously 24 hours per day with the least possible attention, that would be dustless in operation, easy to instal and extend if required, robust in construction, self-cleaning, low in maintenance costs, with all the working parts accessible, easy to operate and control, and with a long working life. This has been achieved by reducing friction between the load, the conveying member, and the trough. The conveying members are malleable iron castings of patented design, connected together with drop forgings. The points of contact of the conveying members with the bottom of the trough are treated with abrasion-resisting metal and run on manganese strips, and it has been proved under exten-

sive running conditions that wear is negligible. The speed of the conveying members is very slow when compared with the speed of either a band or worm conveyor. There are no intermediate bearings either in or out of the path of the load being conveyed, as all bearings are dust-tight and confined to the conveyor ends and out of the path of the load. Inlets and outlets may be fitted where desired. As the load passes slowly through the machine there is no disturbance of the particles, with the result that there is no loss of material and conditions are improved for the operatives.

A further application is the adaptation of these vertical elevators in conjunction with automatic packing machines; several of these machines have been in regular operation for two years at a cement works in Kent, as shown in Fig. 1.

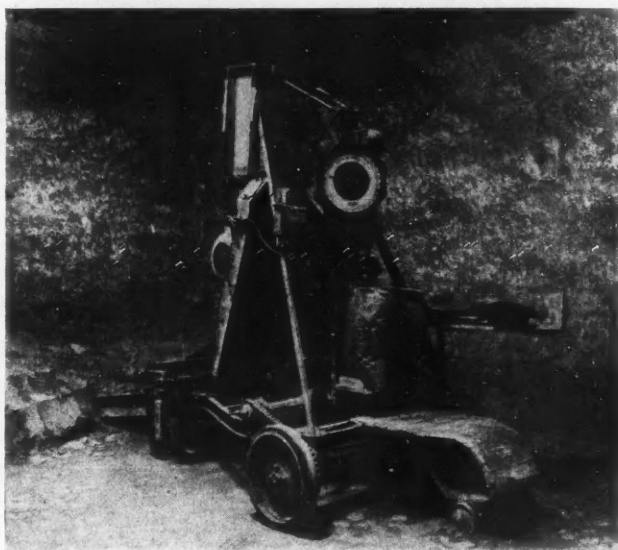


Fig. 1.

Conveyors and elevators are made in sizes ranging from 5 in. to 30 in., the latter being capable of handling over 400 tons of coal per hour. These machines are not limited to straight-line conveying, but can be installed to convey around curves or bends. The conveying action is so gentle that there is no dust even with powdered materials, and as they are totally enclosed the materials are protected from outside dust, moisture, or fumes. The load can be fed into horizontal conveyors at any point or points on either horizontal, inclined, or vertical conveyors. With such a large volume of material flowing through the conveyor, chain speeds can be kept low with correspondingly low maintenance costs. The only power required is that necessary to keep the material flowing,

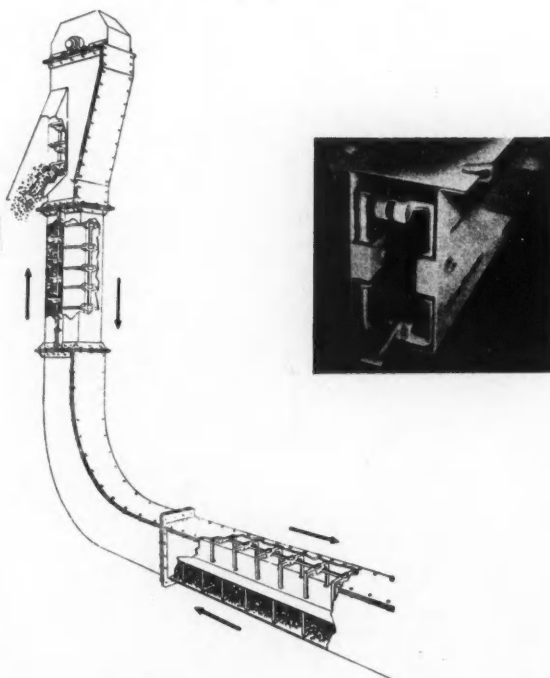


Fig. 2.

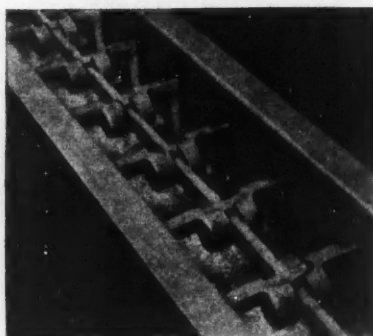


Fig. 3.

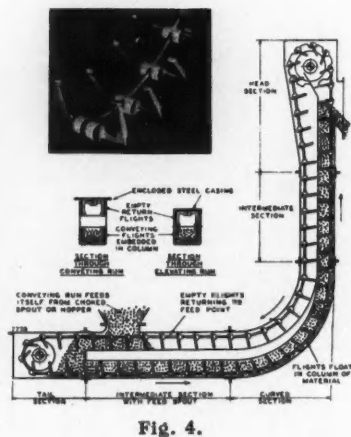


Fig. 4.

plus any useful work done in elevating and the power used to pull the empty return chain.

Fig. 2 shows a section and a diagrammatic view of a machine for handling powdered materials. The material flows through the lower part of the conveyor, while the empty "flights" return along the upper part. A view of a 5-in. conveyor for horizontal or inclined work is given in *Fig. 3*; the material is travelling along the lower part of the trough while the empty flights are returning on smooth guides.

The type shown in *Fig. 4* is for both elevating and conveying. This type can be fed from practically any point on a horizontal or inclined run and discharged at any point on the vertical part of the machine.

Fig. 5 shows a bin discharger which can discharge material in uniform layers from the whole area of the bottom of a bin. The machine consists of an enclosed

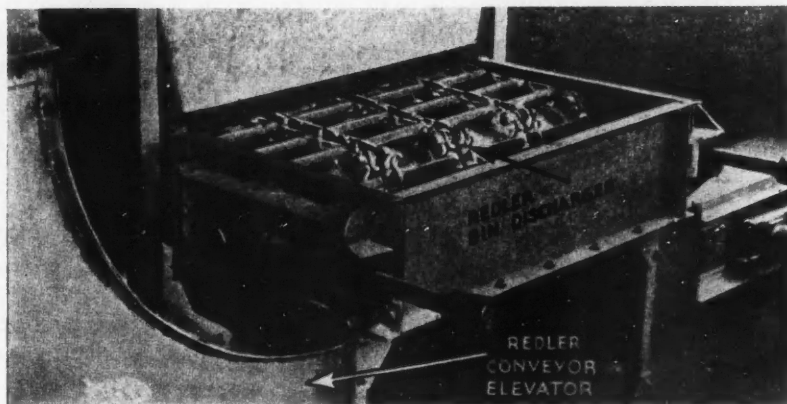


Fig. 5.

steel casing in which one or more parallel strands of flat-type measuring flights are pulled side by side across the flat plate that acts as the bottom of the bin. The drawing shows how the chains slice a layer of uniform thickness from the bottom of the column of material in the bin. As the material is cut loose, it drops through a series of cross slots and is deposited in layers on the lower or returning run of flights. These lower chains carry down a slope gauged to discharge an equal volume of material from each slot. In this way the material is fed from the bin in accurate volume and without separation of mixed ingredients. By using one or more strands of the flat-type chain (5 in. and 9 in. widths) bin dischargers can be made in widths and lengths to suit any bin and volume required. Each discharger is usually made especially to suit the bin and material with which it is to operate.

The patentees and manufacturers of the plant are Messrs. Redler Patents.

The System Lime—Boric Acid—Silica.

THE system $\text{CaO-B}_2\text{O}_3\text{-SiO}_2$ is a fundamental one in ceramics, for the high silica-boric oxide portion may serve as a starting point for investigations of borosilicate glasses, enamels and ceramic glazes. As a result of observations of the effect of small quantities of boric oxide on calcium silicates occurring in Portland cement, which apparently indicated the possibility of producing a "well-burned" clinker at a relatively low temperature, Messrs. E. P. Flint and Lansing S. Wells, of the United States National Bureau of Standards, have made a series of investigations since the year 1930. The tests are described and the results given in Research Paper RP941 of the Bureau, obtainable from the Superintendent of Documents, Washington, D.C., price 10 cents. After describing the research work, the report states:

Dicalcium silicate occurs in Portland cement in the unstable beta modification which possesses desirable hydraulic properties, whereas, in its low-temperature gamma modification, the compound is practically non-hydraulic. The beta-gamma inversion for the pure compound normally occurs at 675 deg. C. with such rapidity that it is difficult to prepare the beta form in appreciable quantities even on quenching from temperatures of over 1,000 deg. C. However, it was first noticed by Bates and Klein¹ that the presence of less than 1 per cent. of B_2O_3 or Ca_2O_3 prevented the inversion and that the former oxide seemed to effect a marked lowering of the fusion temperature of the compound.

Further studies carried on by E. T. Carlson² showed that progressive lowering of the alpha-beta inversion temperature of dicalcium silicate occurred on the addition of 0.5 to 5 per cent. of B_2O_3 to the compound. Lowering of the indexes of dicalcium silicate was also noted. It was concluded that these effects probably indicated solid solution of boric oxide in the silicate. The results of the present investigation have verified this conclusion and partially fixed the limits of solid solution of the calcium borates in dicalcium silicate. No determinations of the beta-gamma inversion temperature were made, but it seems probable that this inversion is rendered very sluggish or inhibited completely by the existence of the solid solutions.

The non-appearance of tricalcium silicate as a primary phase in the system $\text{CaO-B}_2\text{O}_3\text{-SiO}_2$ is of significance with reference to the possible use of boric oxide to lower clinkering temperatures of the Portland cement raw mix. The region where this compound might be expected is occupied by the ternary compound $5\text{CaO.B}_2\text{O}_3.\text{SiO}_2$. This compound may be considered as formed by the combination of one mol. of tricalcium silicate with one mol. of dicalcium borate. A small amount of the ternary compound was finely ground, gauged with water to a stiff paste, and allowed to stand for some days. No setting was observed. It appears therefore that the compound does not possess hydraulic properties, although the question has not yet been sufficiently investigated to verify this indication.

¹ P. H. Bates and A. A. Klein, "Properties of the calcium silicates and calcium aluminate occurring in normal Portland cement," Tech. Pap. BS8 (1917), T78.

² E. T. Carlson, unpublished data.

Furthermore it was found by Carlson that, although the addition of boric oxide to binary mixtures of CaO and SiO_2 , or of CaO and Al_2O_3 , promoted combination of these constituents on heating, the addition of boric oxide to ternary mixtures of CaO , SiO_2 , and Al_2O_3 , with or without the addition of Fe_2O_3 and MgO , inhibited combination. That is, clinkers produced by heating CaO , SiO_2 , Al_2O_3 mixtures alone contained much less uncombined lime than corresponding mixtures to which boric oxide had been added, and the percentage of free lime in the clinkers was found to increase with increase in their B_2O_3 content. It is probable that there is a considerable broadening of the lime field at various B_2O_3 levels in the quaternary system $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2\text{-B}_2\text{O}_3$.

These considerations indicate that the addition of appreciable quantities of boric oxide to the Portland cement raw mix would not be desirable.

Refractory Concrete.

INFORMATION on a new application of aluminous cement is given in a booklet issued by the Lafarge Aluminous Cement Co., Ltd., describing a refractory concrete which will be stable under load up to a temperature of 1,300 deg. C. The concrete is made with mixtures of aluminous cement and crushed firebrick of suitable grading. It requires no pre-firing and can be used for in situ furnace work or in precast blocks. It is claimed that it can be brought up to working temperatures twenty-four hours after moulding, and does not spall with wide fluctuations of temperature. If chrome or chrome-magnesite firebrick is used the concrete is claimed to withstand temperatures up to 1,600 deg. C. A refractory mortar can also be made using aluminous cement and firebrick crushed to sand size. This method of making refractory concrete should have some appeal for those such as cement manufacturers, who at times have quantities of scrap firebrick available. The following notes on this type of refractory are compiled from the book. Recommended proportions are 3 cu. ft. of coarse aggregate ($\frac{3}{4}$ in. to $\frac{1}{2}$ in.), 2 cu. ft. of fine aggregate ($\frac{1}{8}$ in. down), to 1 cu. ft. (90 lb.) of aluminous cement. A refractory mortar is made with brick grog $\frac{1}{8}$ in. down in the proportion of from 2½ to 4 cu. ft. of aggregate to 90 lb. of aluminous cement. Higher proportions of cement increase workability and strength but lower the refractoriness of the concrete or mortar. The aggregate is porous, and should be soaked before mixing. The refractory concrete has the same rapid hardening characteristics as normal aluminous cement concrete, and can be exposed to high temperatures twenty-four hours after making. Sudden changes of temperature, such as are caused by quenching the hot refractory concrete with cold water, do not cause spalling. The crushing strength of the refractory concrete when hot ranges from 1,120 to 2,310 lb. per square inch at a temperature of 1,200 deg. C. with a cement content ranging from 13 per cent. to 32 per cent. by weight. The crushing strength of 1 : 2½ refractory mortar ranges from 3,360 lb. per square inch at 500 deg. C. to 2,032 lb. per square inch at 1,200 deg. C. when two days old. It is stated that there is no shrinkage on drying, and that the expansion on heating is the same as that of the firebrick aggregate.

Some ten years ago refractory concrete was used for lining furnace doors in this country, and since that date it has been used for kiln floors, annealing oven doors, coke stoves, coke cooling chambers, the bases of furnace trucks, etc.

Properties of Lime-Cement Mortars.

LIME is often added to cement mortars to improve their working properties. Usually more attention is paid to the proportions of the mix than to the properties of the lime and the manner in which it is used. Consequently, an investigation of certain properties of lime putties in relation to the resultant properties of lime and cement-lime mortars made from them has been undertaken by the United States Bureau of Standards.

The effect of the time of soaking on the soundness of lime putties was also investigated. It was found that out of 43 limes tested by the autoclave method, 7 of 24 hydrated limes and 8 of 19 pulverised quicklimes gave putties which were classified as unsound at the end of one day of soaking. At the end of three days of soaking, four putties from the hydrated limes and four from the quicklimes were unsound.

The plasticity values of the putties determined with the Emley plasticimeter varied from 50 to more than 600. Putties of widely varying plasticity were then used in preparing lime-sand mortars (1 part lime to 3 parts sand by weight) and adjusted to a flow of 130 per cent. as measured on a standard 10-inch flow table. The flow was again determined after one minute of suction (equivalent to a head of 2 inches of mercury) had been applied by means of a suction device designed to remove water from the mortar much as is done by a porous body. The flow after suction varied from 73 to 117 per cent. In general, the flow after suction is dependent to a considerable extent on the plasticity of the putty used in preparing the mortar. This also proved to be true after a suction period of ten minutes.

Cement-lime mortars of varying proportions were also prepared using lime putties of varying plasticity and cements of medium and high specific surface areas. The mortars were brought to an initial flow of 130 per cent. and the flow again determined after one minute of suction. The results showed that the higher flows after suction were obtained with the more plastic limes and that the kind of lime used is of more importance than the proportions in securing a high flow after suction. Furthermore, limes made into putties produced mortars of higher flows after suction than did hydrated limes not soaked as putties. The substitution of the proper lime putty for cement produced higher flows after suction than could be obtained by the use of a cement of high specific surface.

The complete report of this work is given in the Bureau's Journal of Research for December, 1936 (RP952 by Lansing S. Wells, Dana L. Bishop, and D. Watstein).
